Distribution and covariation of water vapor and clouds in the trades

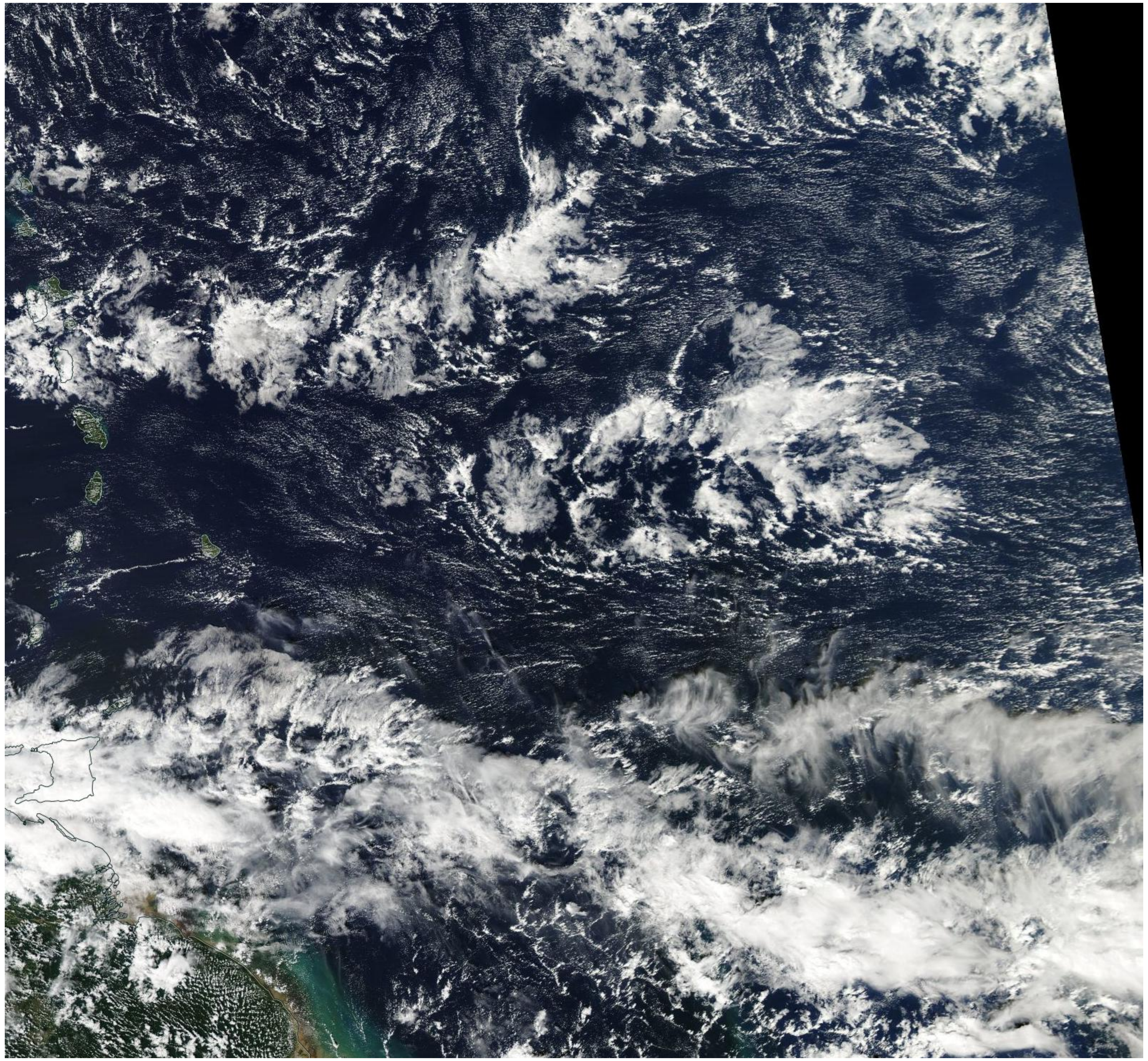
Ann Kristin Naumann (MPI-M)
Christoph Kiemle (DLR)

water vapor varies on the regional scale

62 W

48 W

20 N



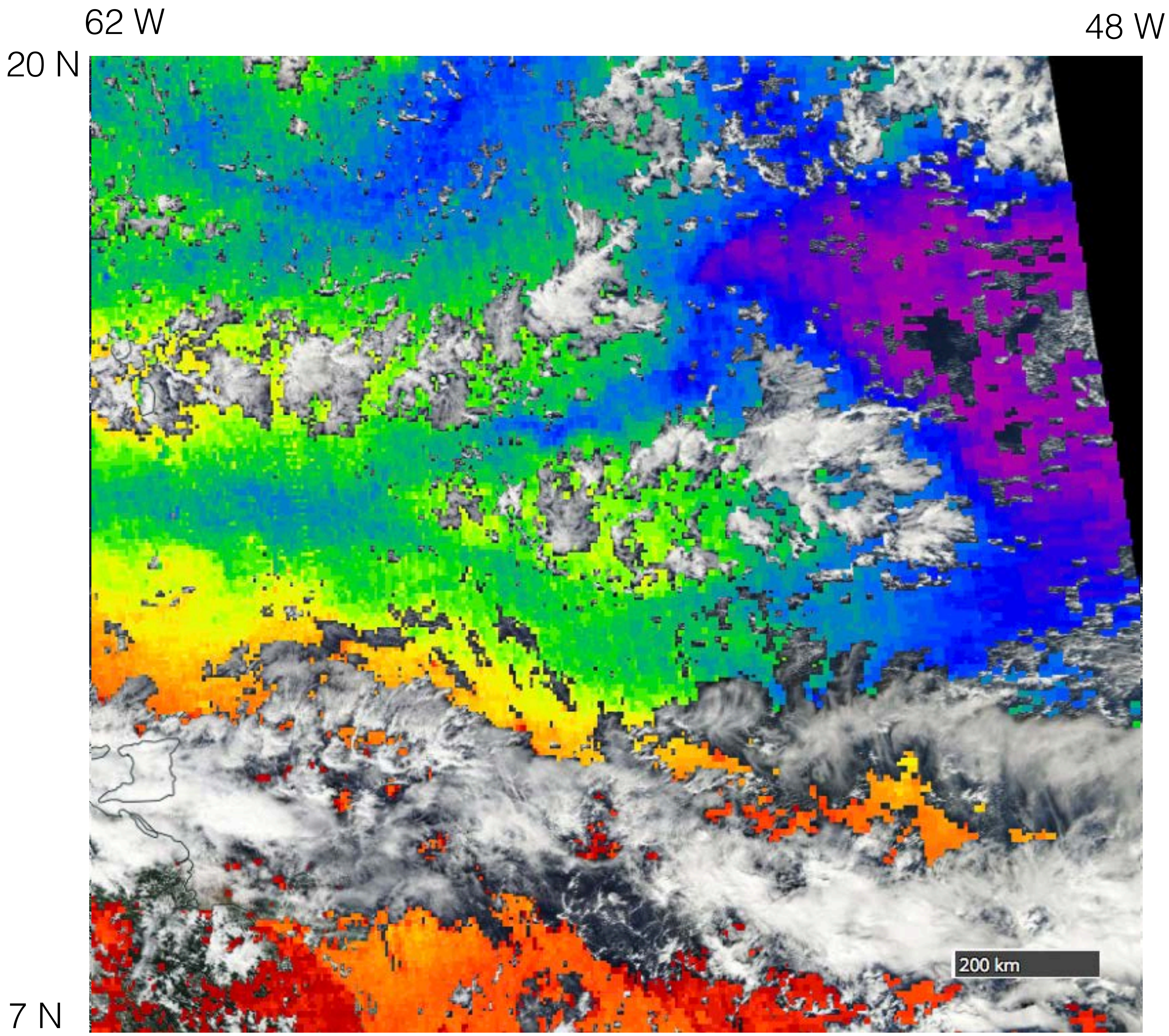
7 N

- strong relation between WVP and precipitation (e.g., Bretherton et al. 2004, Holloway and Neelin 2009, Nuijens et al. 2009)
- cloud layer humidity determines dilution of clouds by entrainment
- vertical distribution of moisture determines radiative cooling

water vapor path & reflectance
purple: 15 kg/m^2 to red: 50 kg/m^2

Aqua Modis on 11. Dec 2013
worldview.earthdata.nasa.gov

water vapor varies on the regional scale



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Water vapor variability in the tropical Atlantic

What is the vertical structure and covariation of water vapor and clouds in the trades?

Are models able to represent the observed relationship correctly?

NARVAL observations

Lidar:
high spectral resolution lidar **WALES** measuring water vapor with ~2.5 km horizontal and 200 m vertical resolution
(Wirth et al. 2009, Kiemle et al. 2017, Gutleben et al. 2019)

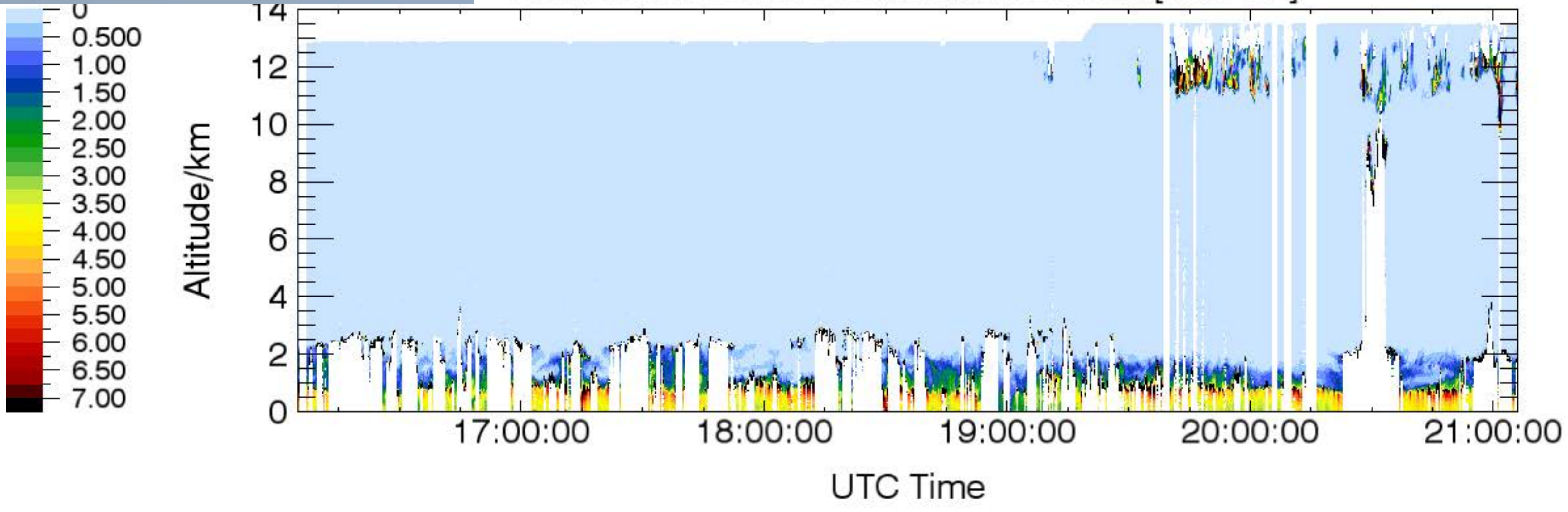
1) Only use profiles with more than half of the data point below the max cloud top height. (here: 3 km, 35 % valid)

2) When the lidar signal is extinct:
   Minimum: lidar shadows are filled by neighboring values
   Maximum: lidar shadows above the LCL set to saturation, remaining areas are filled by neighboring values

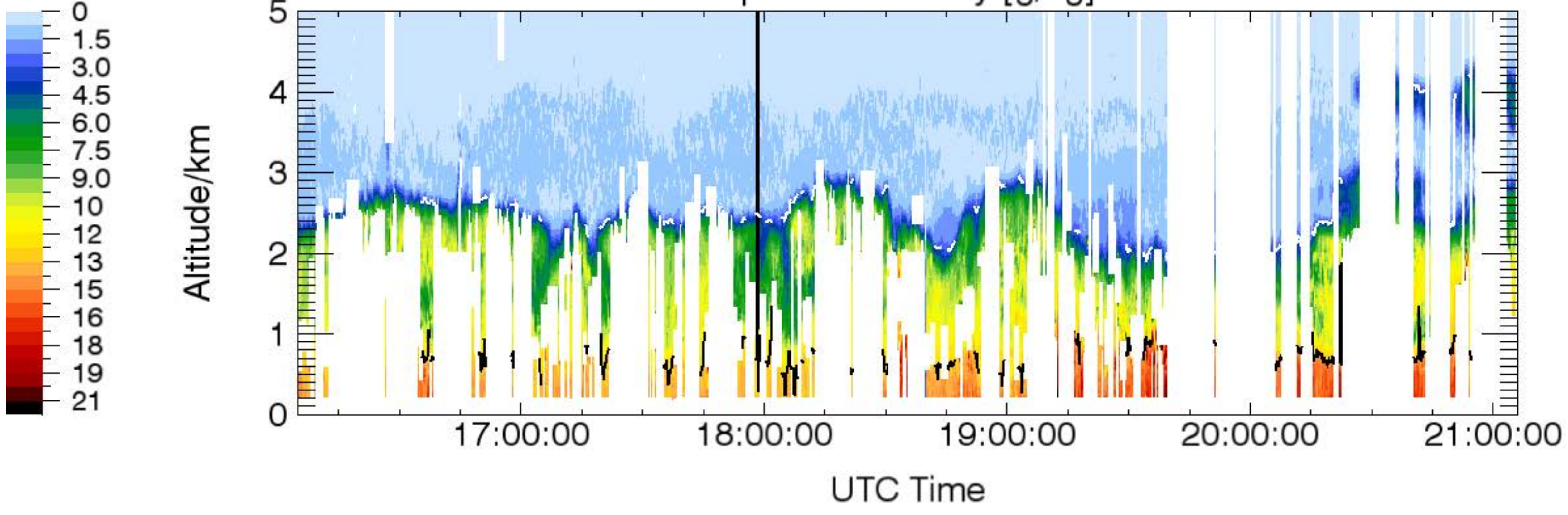
Radiometer:
HAMP measures WVP with ~200 m horizontal resolution
(Mech et al. 2014, Jacob et al. 2019)

NARVAL-1: 11.12.2013

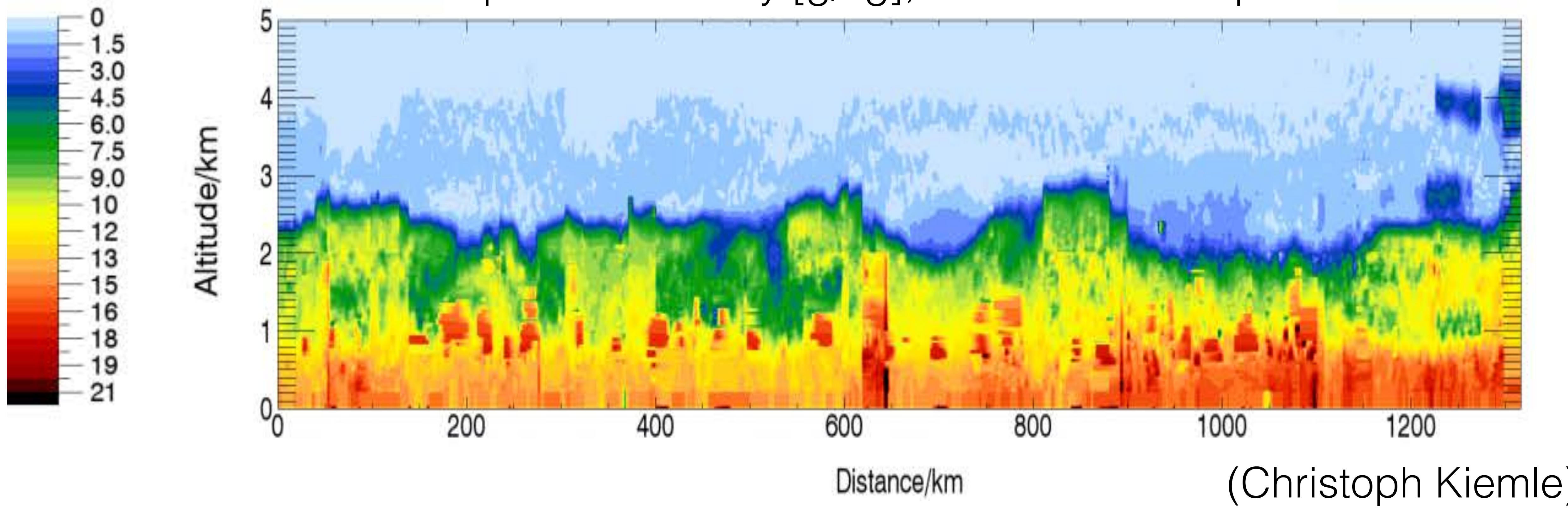
HSRL Backscatter Coefficient at 532 nm [Mm^{-1} sr^{-1}]



Specific Humidity [g/kg]

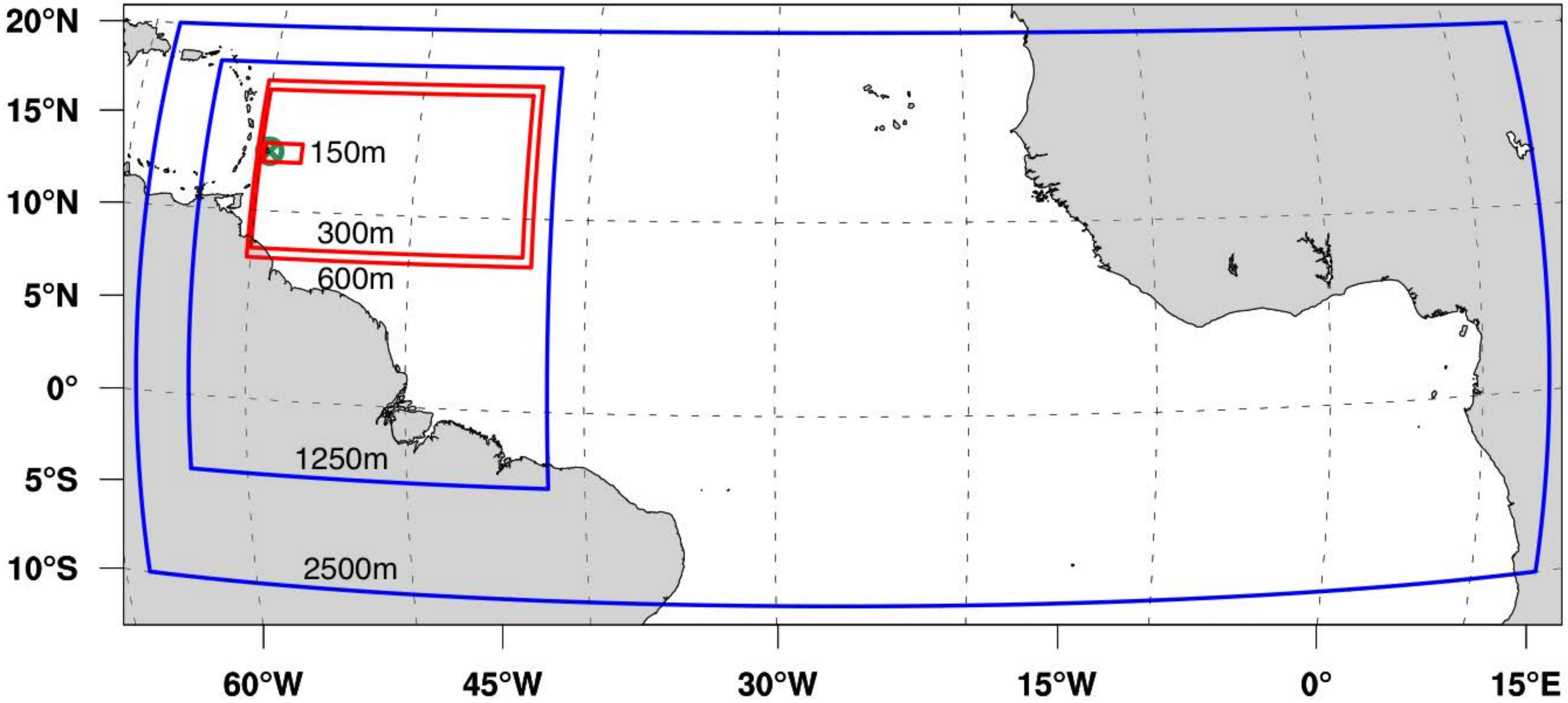


specific humidity [g/kg]; minimum assumption



(Christoph Kiemle)

NARVAL simulations



ICON-SRM (storm resolving model)
at grid spacings of 2.5 km and 1.25 km
(Klocke et al., 2017)

ICON-LEM (large eddy model)
at grid spacings of 600 m and 300 m
(Stevens et al., 2019)

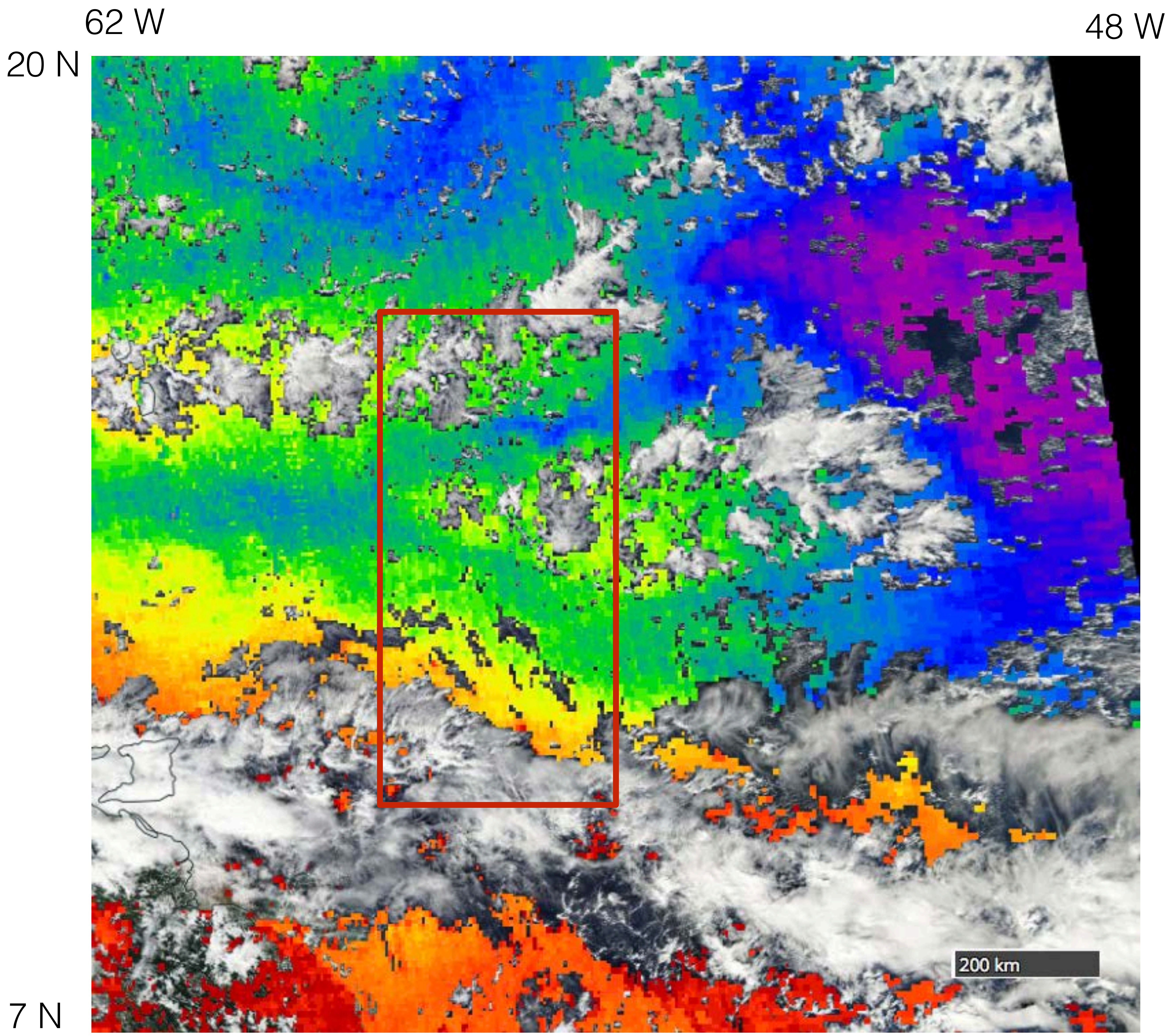
all simulations **without convective parameterization**
SRM with cloud cover parameterization

realistic initial and boundary conditions:
ECMWF reanalysis

one-way nesting of higher resolution simulations in low resolution simulations

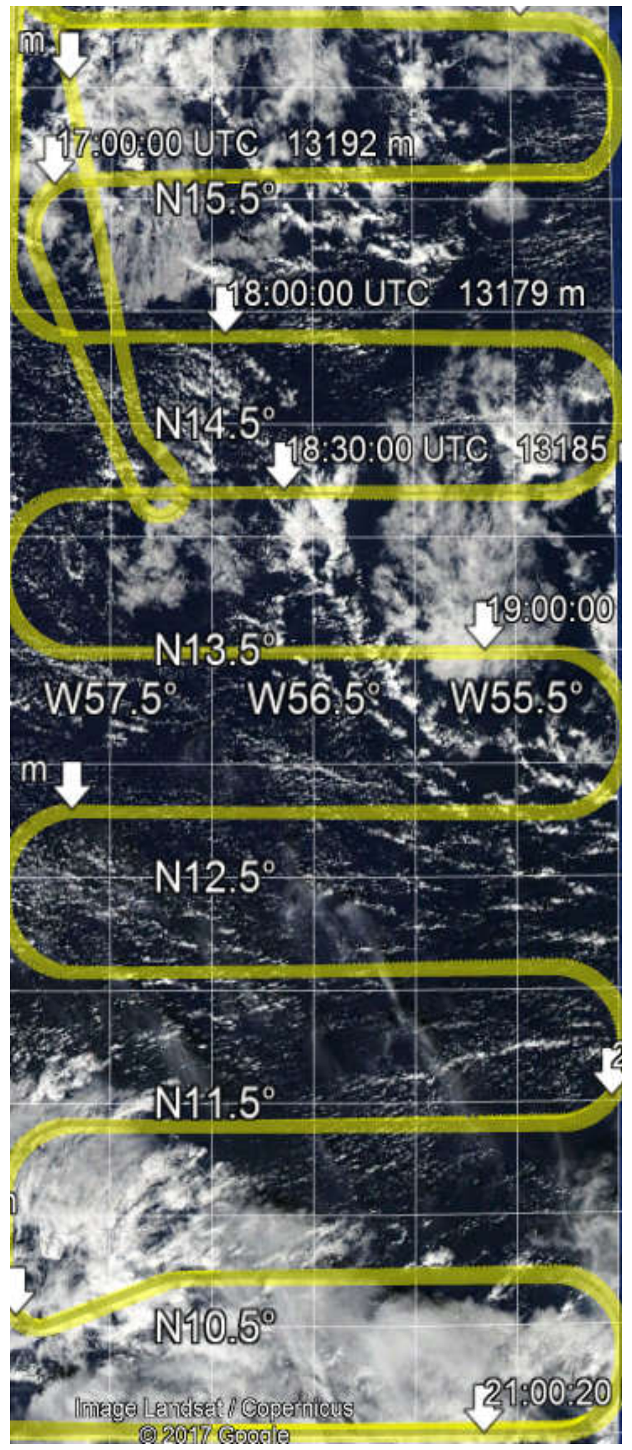
ICON-SRM simulations start at 0 UTC
ICON-LEM simulations start at 9 UTC

qualitative comparison for 11.12.2013

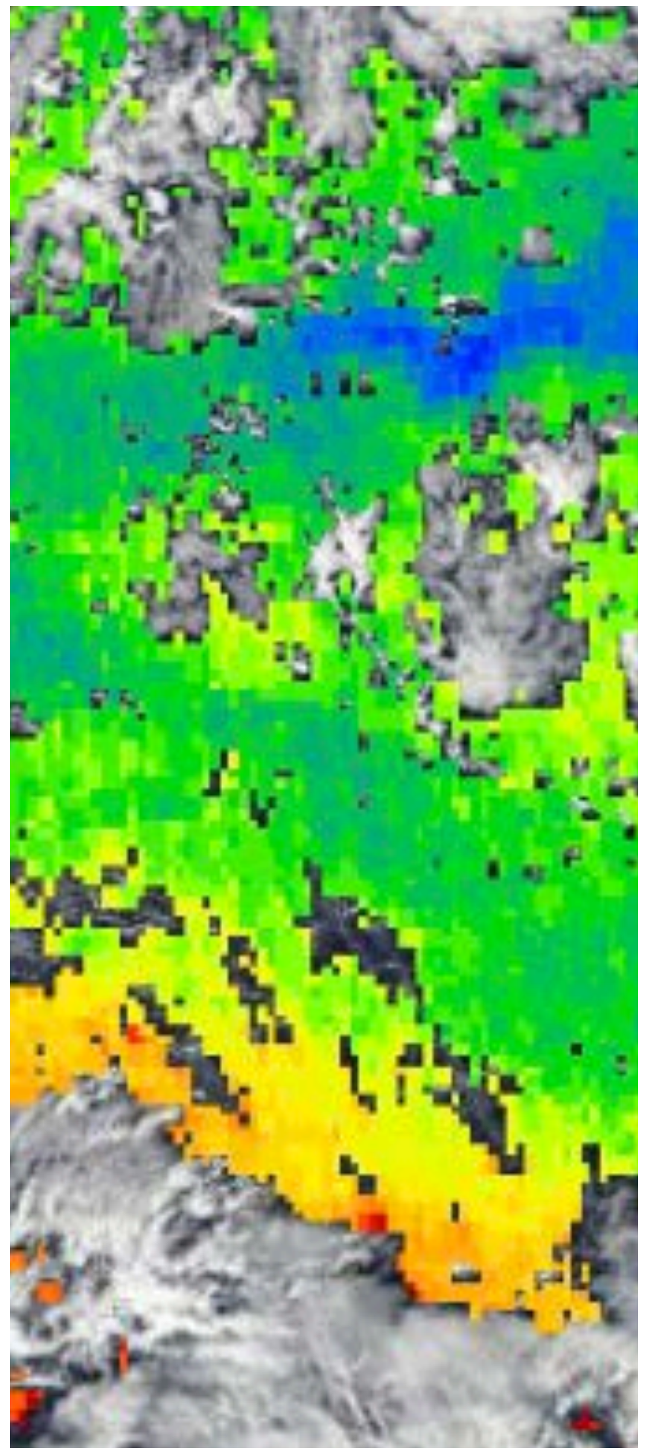


qualitative comparison for 11.12.2013

MODIS Aqua
17:25 UTC

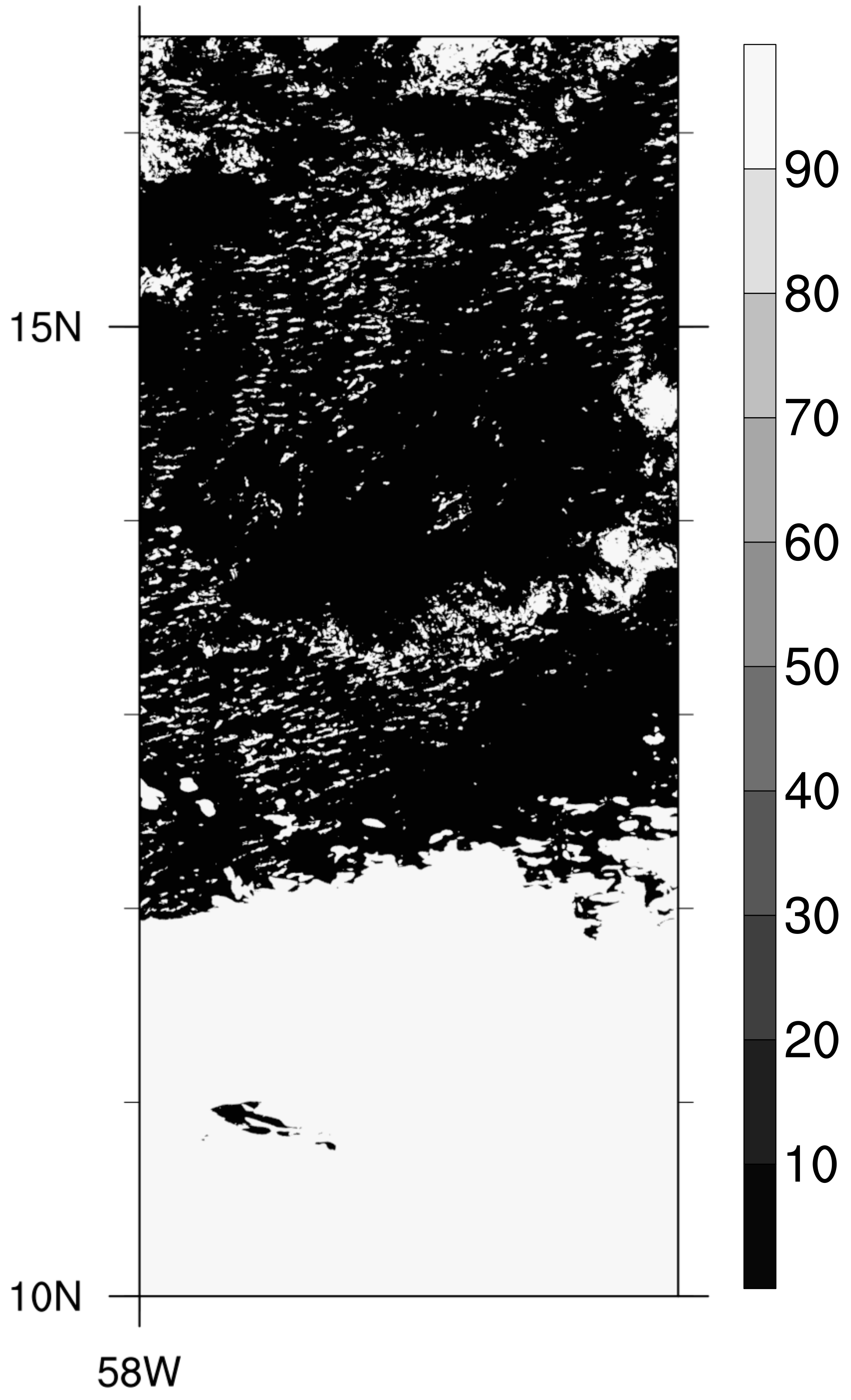


MODIS Aqua
17:25 UTC

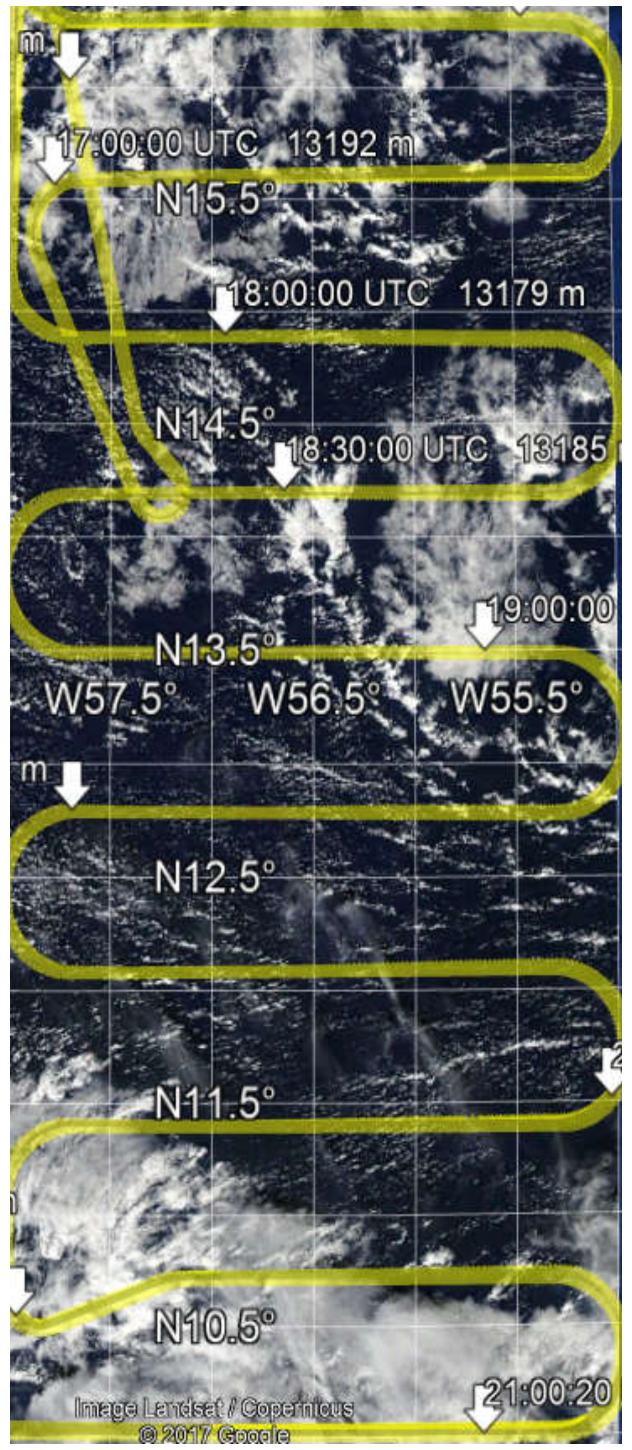


qualitative comparison for 11.12.2013

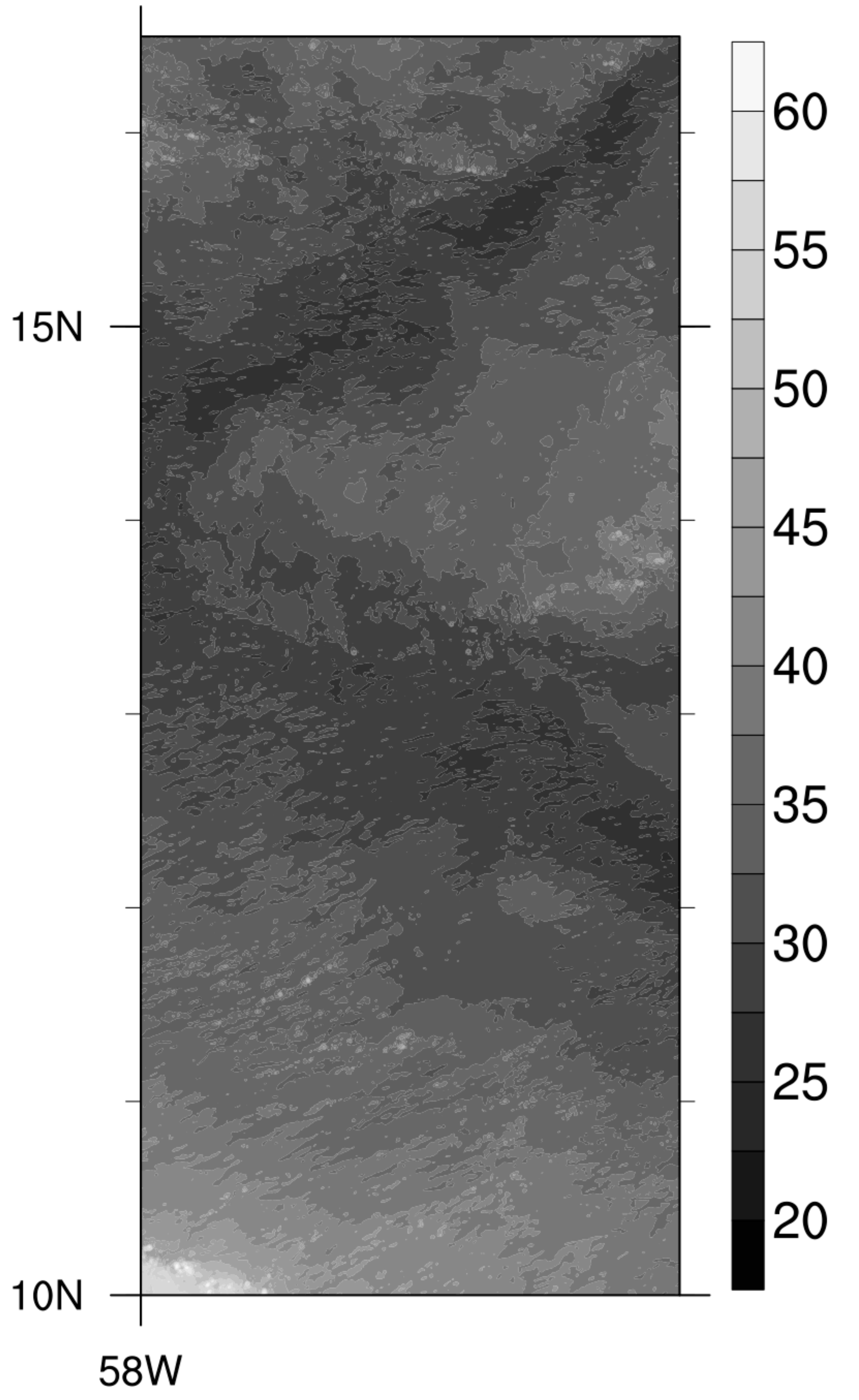
ICON-LEM 300 m
time:17:00 UTC
total cloud cover [%]



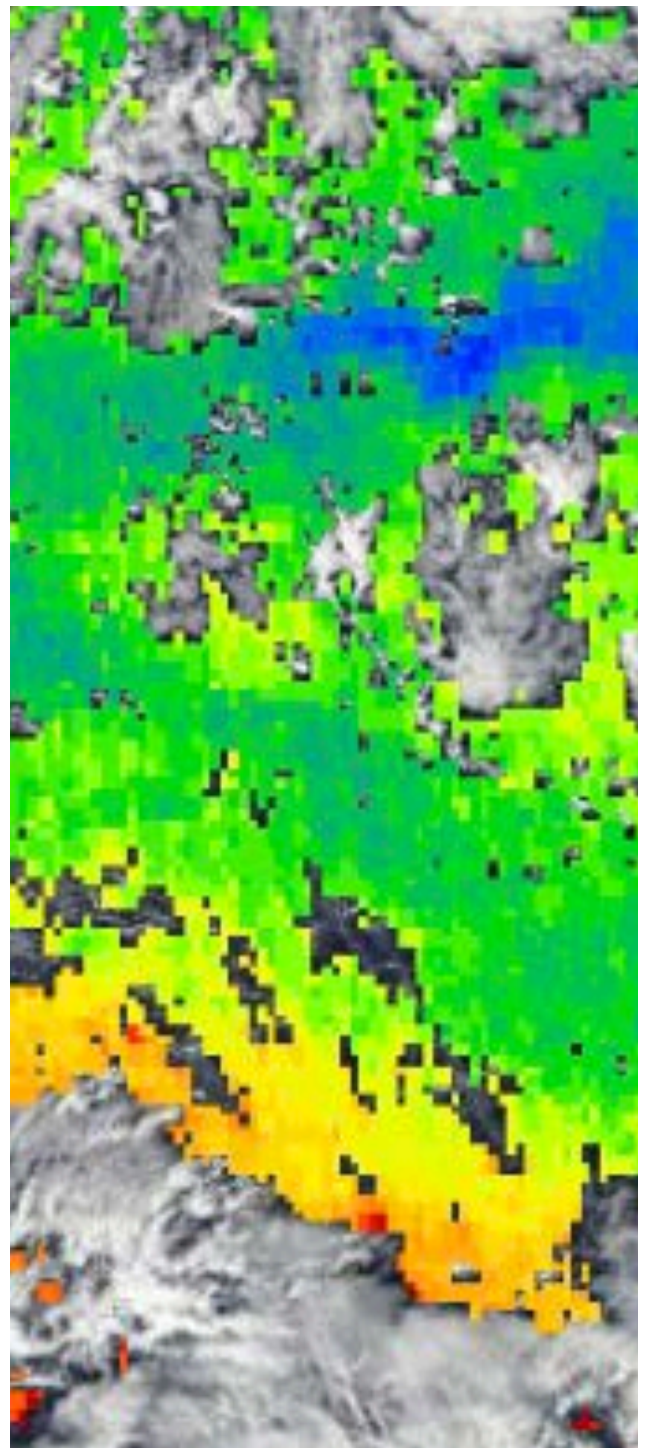
MODIS Aqua
17:25 UTC



ICON-LEM 300 m
time: 17 UTC
WVP [kg m-2]



MODIS Aqua
17:25 UTC



spanning the moisture space

How do we bring lidar data and model results together?

- no co-location of clouds in real world and model world

➡ compare statistics: moisture space
(Bretherton et al. 2005, Schulz and Stevens 2018)

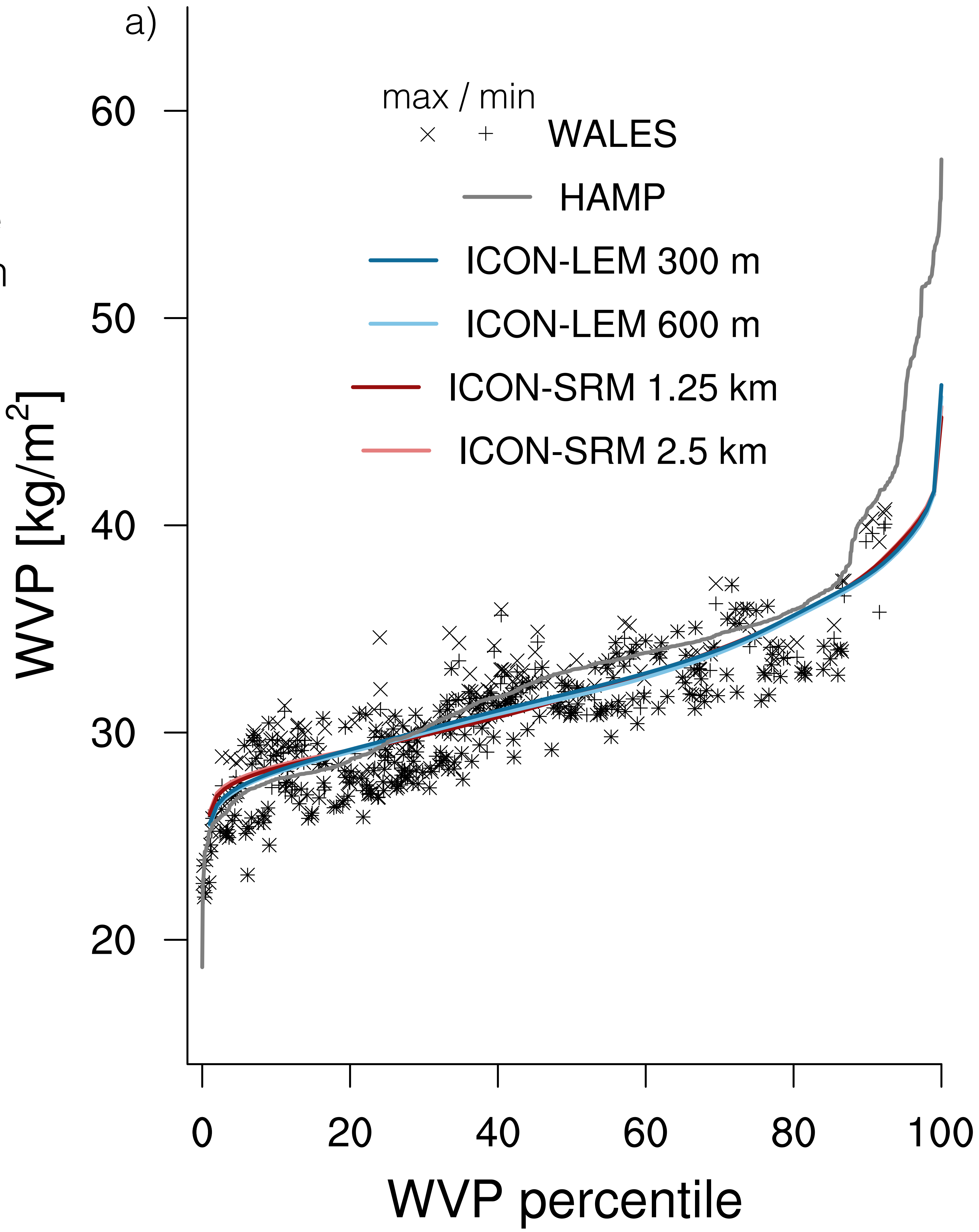
- lidar profiles have gaps where there are (thick) clouds

➡ spanning the moisture space with HAMP

spanning the moisture space

11.12.2013

WALES can be co-located with HAMP



spanning the moisture space

11.12.2013

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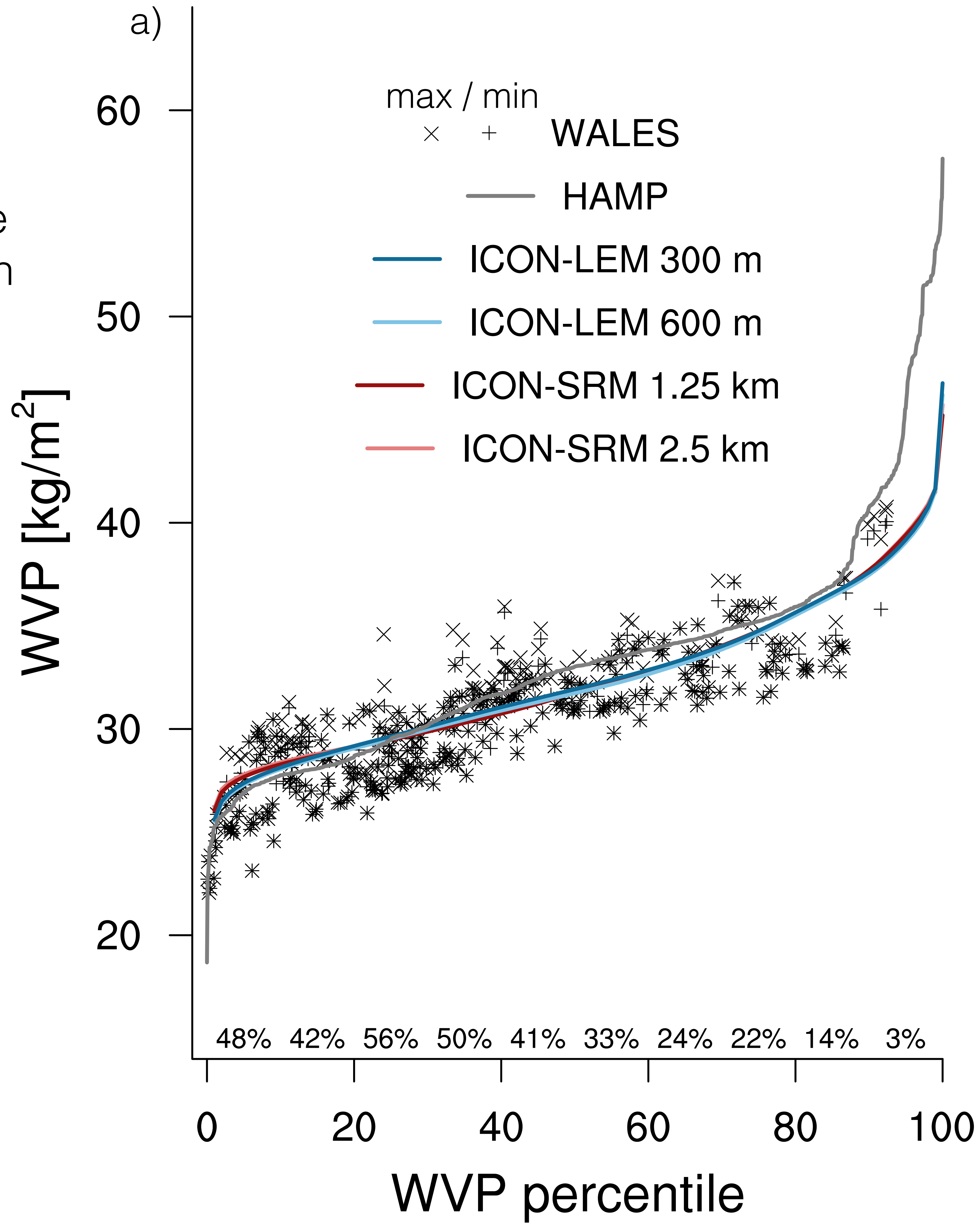

spanning the moisture space

11.12.2013

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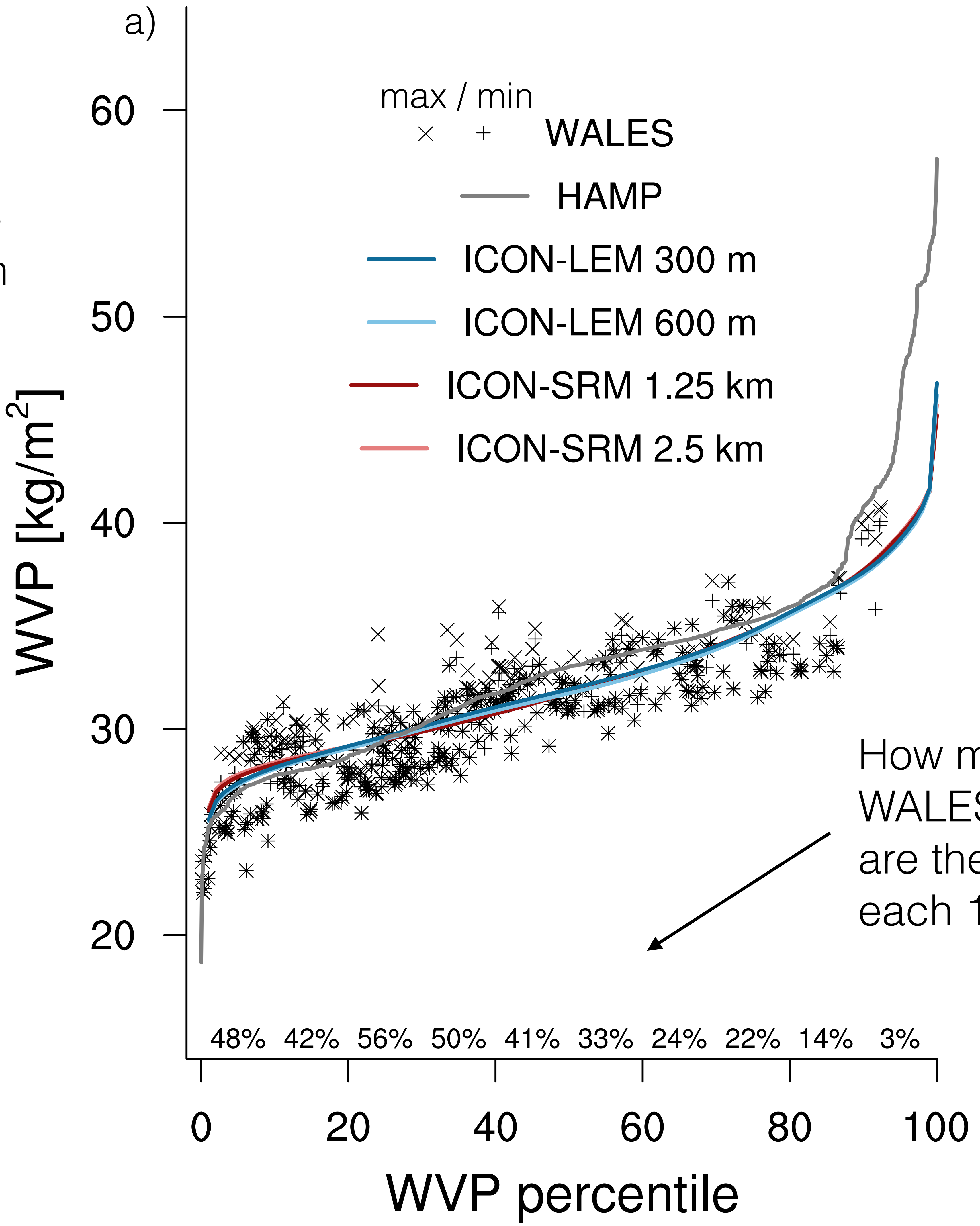
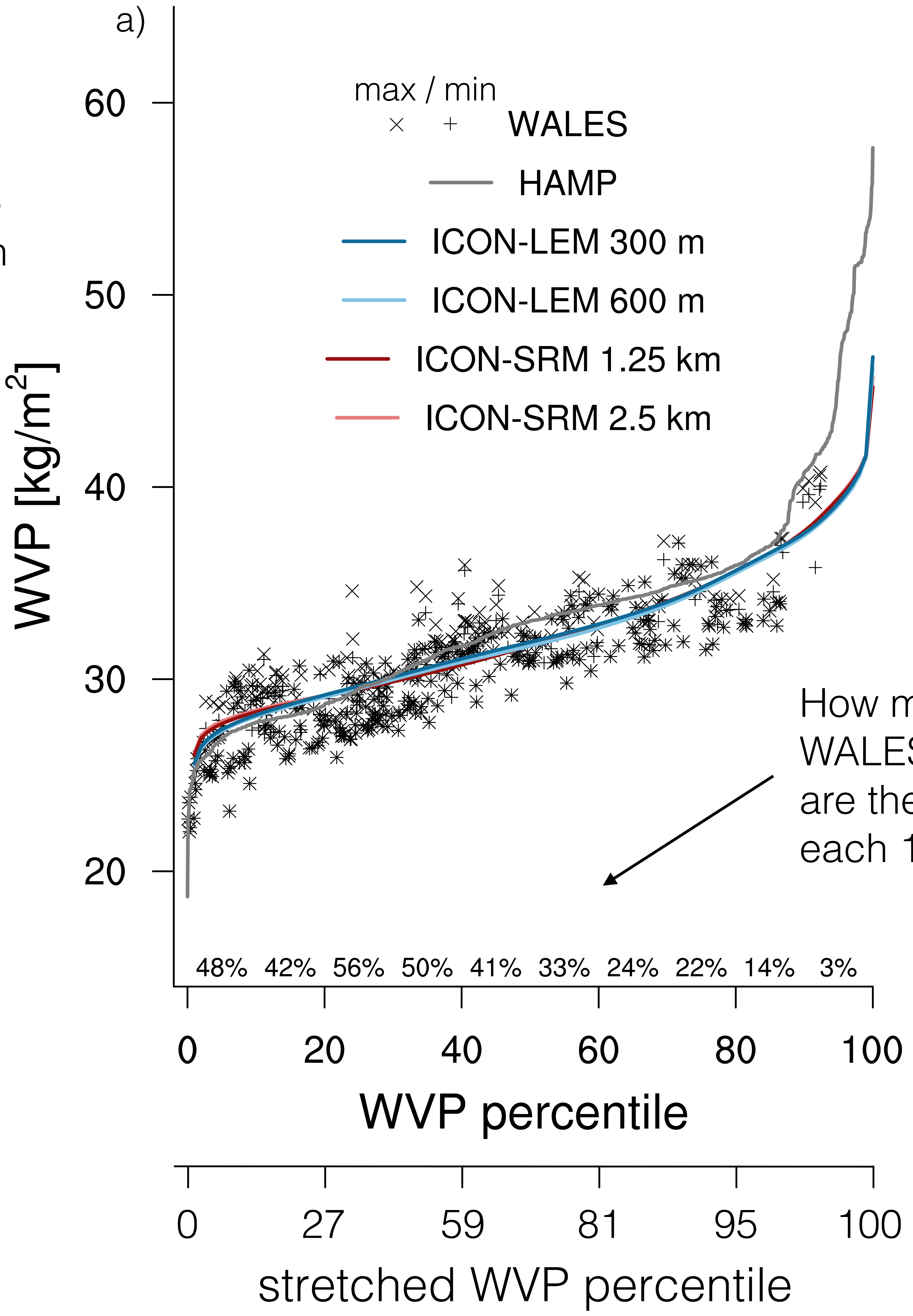


How many valid WALES profiles are there for each 10-% bin?

spanning the moisture space

11.12.2013

WALES can be co-located with HAMP

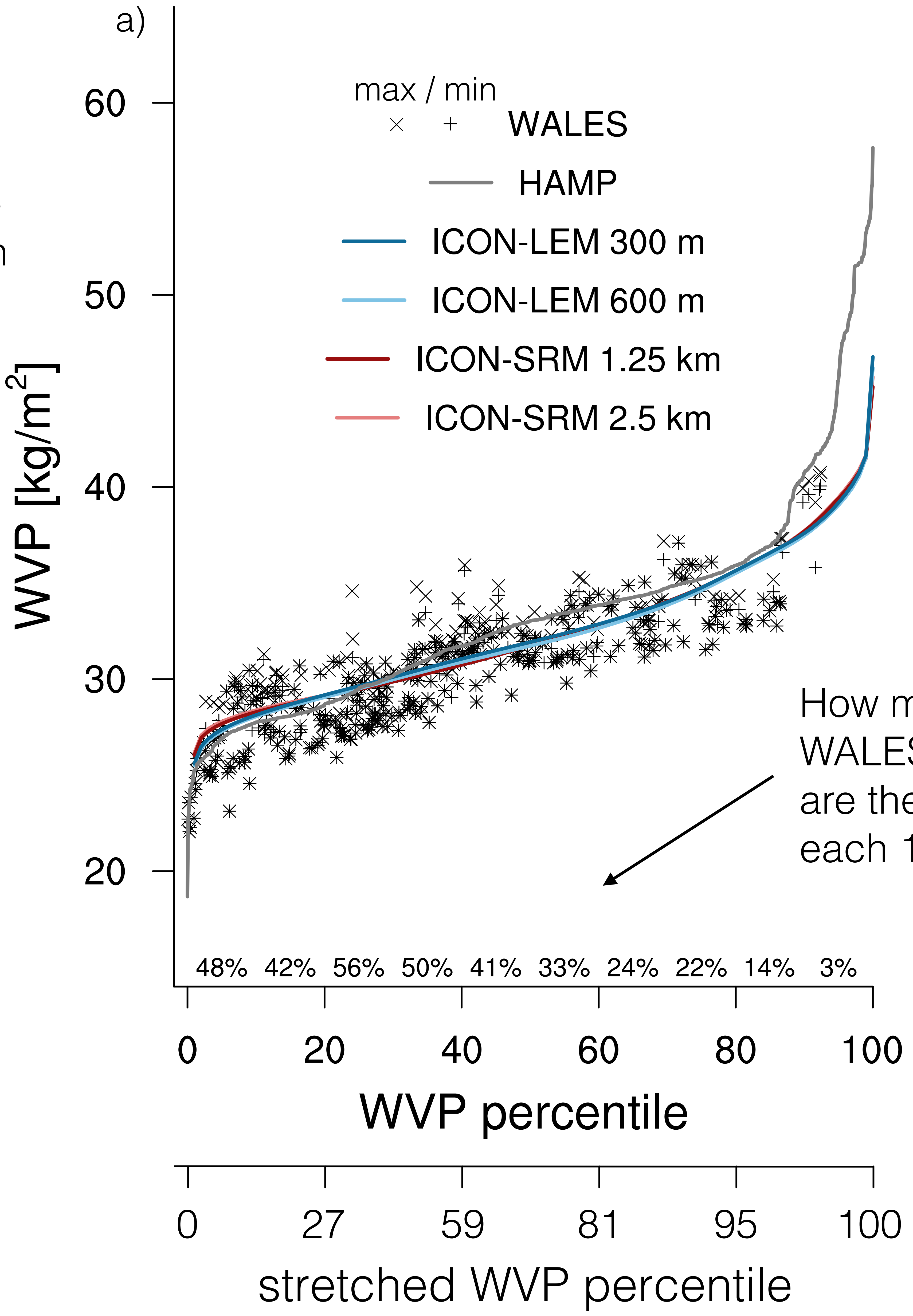


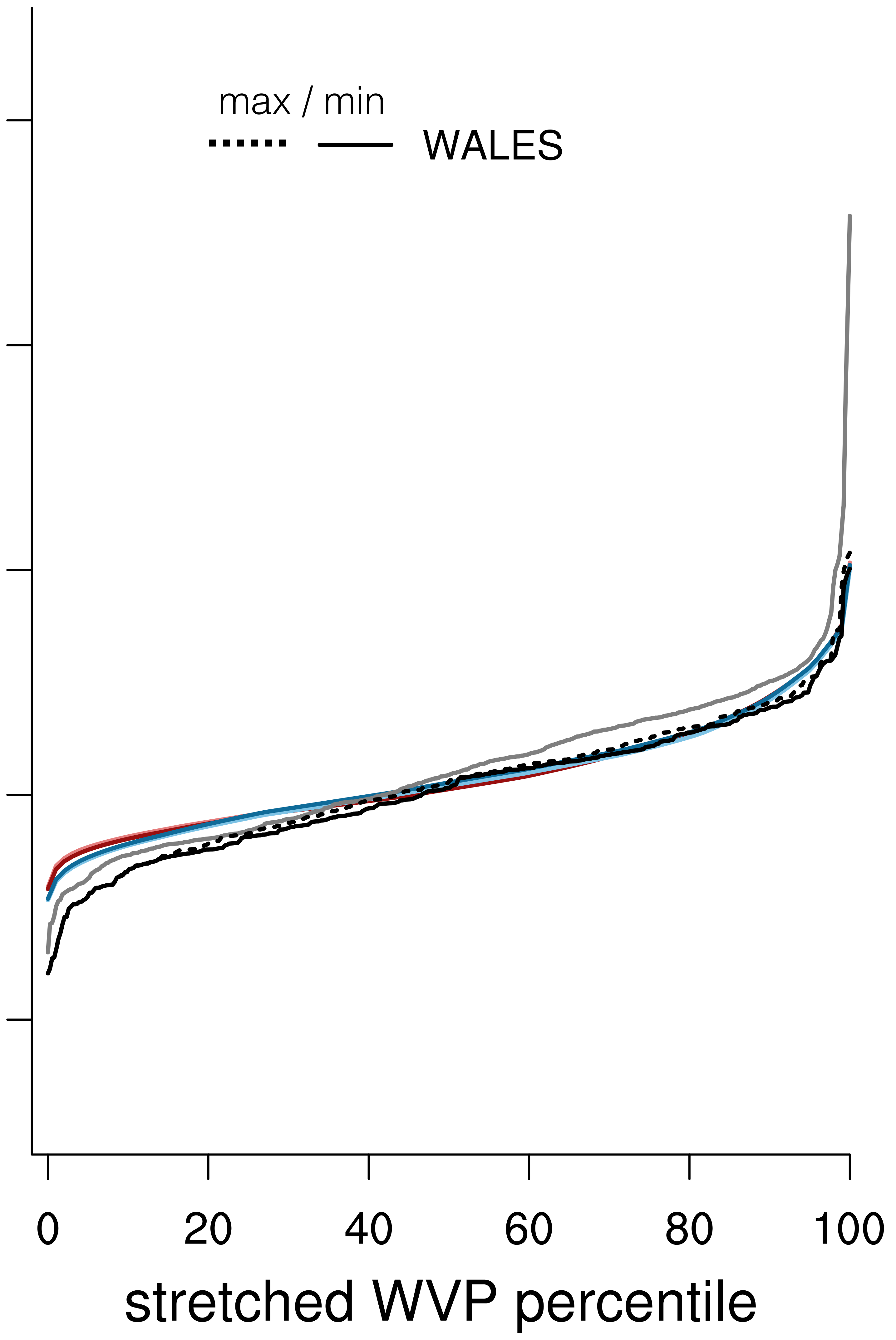
How many valid WALES profiles are there for each 10-% bin?

spanning the moisture space

11.12.2013

WALES can be co-located with HAMP



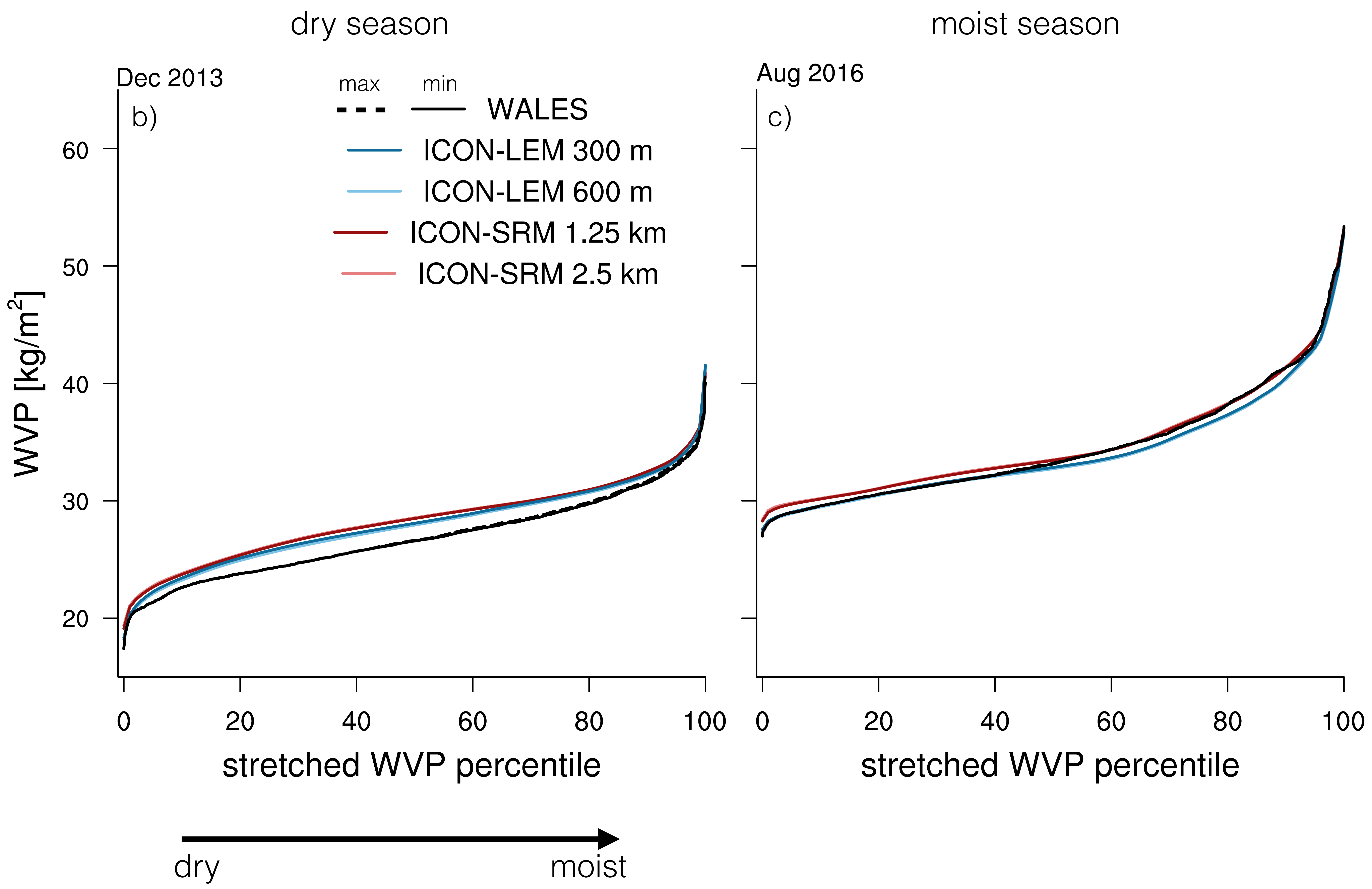


For a fair comparison with WALES only use X % of data from ICON and HAMP for each 10-% bin.

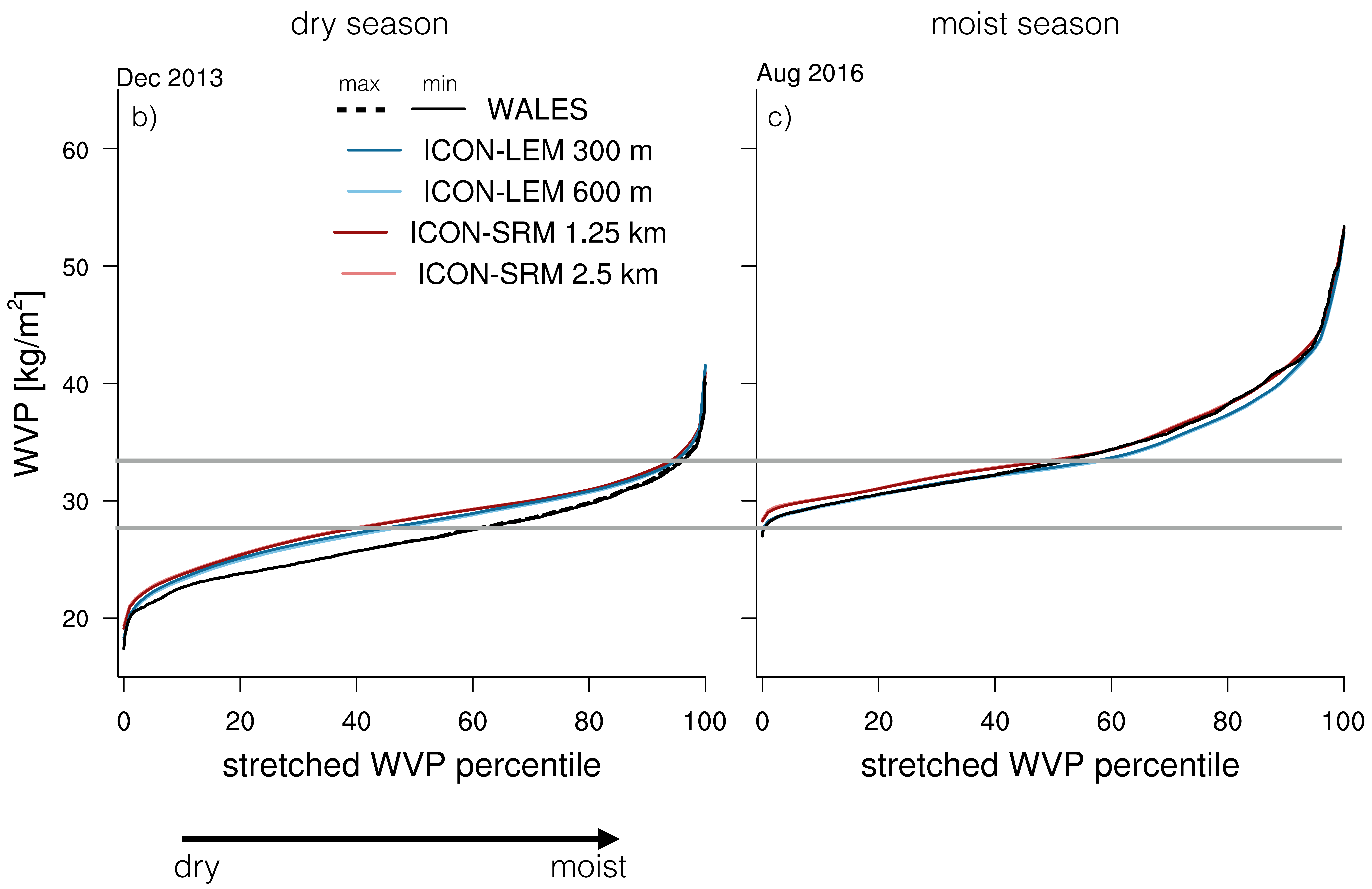
➡ stretched x axis

- moist model bias in dry regions
- no resolution dependence

differences in seasons captured well



differences in seasons captured well

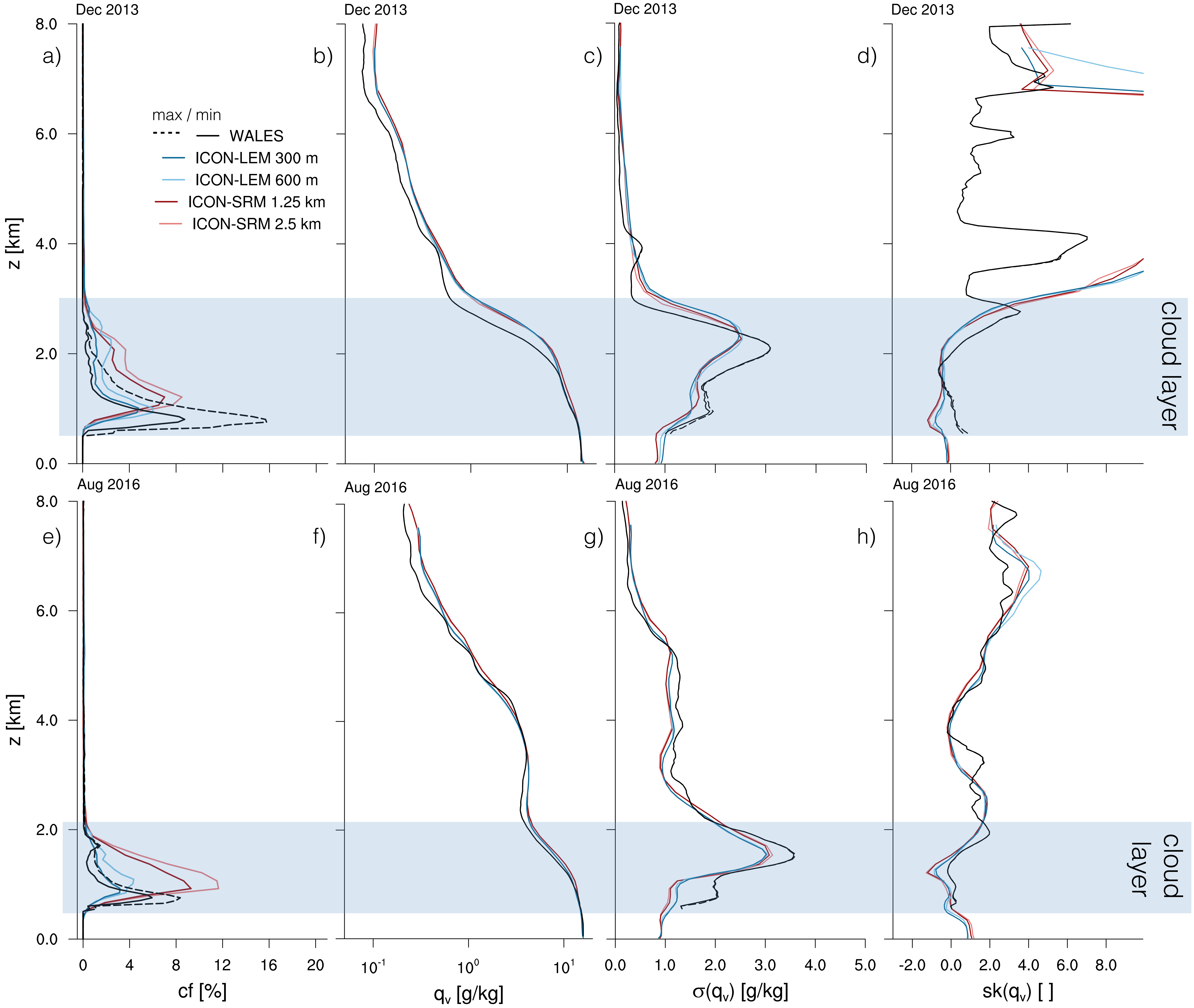


Dec 2013

dry season

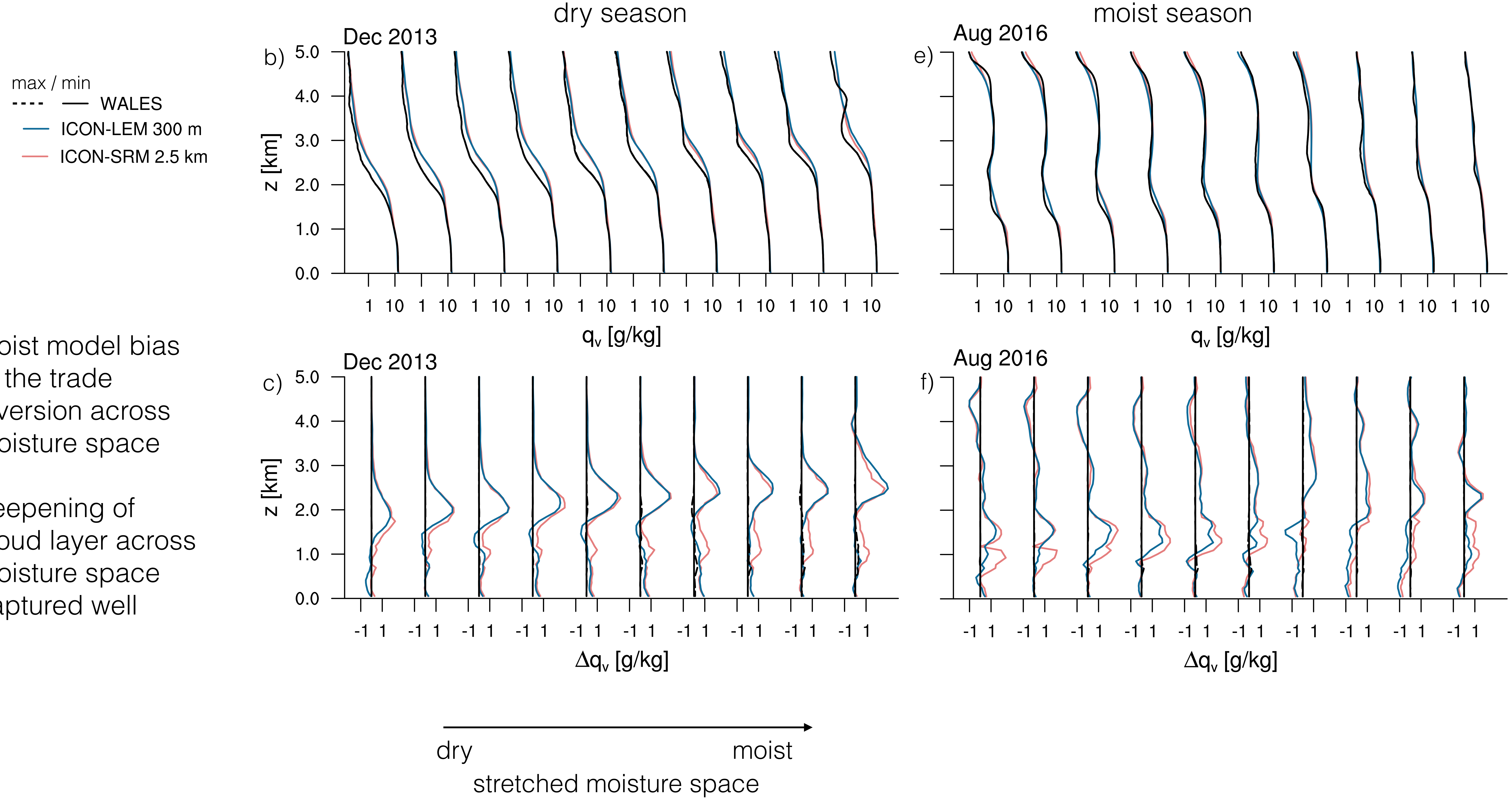
Aug 2016

moist season



- modeled height of maximum cloud fraction is too high
- moist model bias at the trade inversion
- shape of modeled variance captured well but values tend to be too low
- different sign for skewness at cloud base

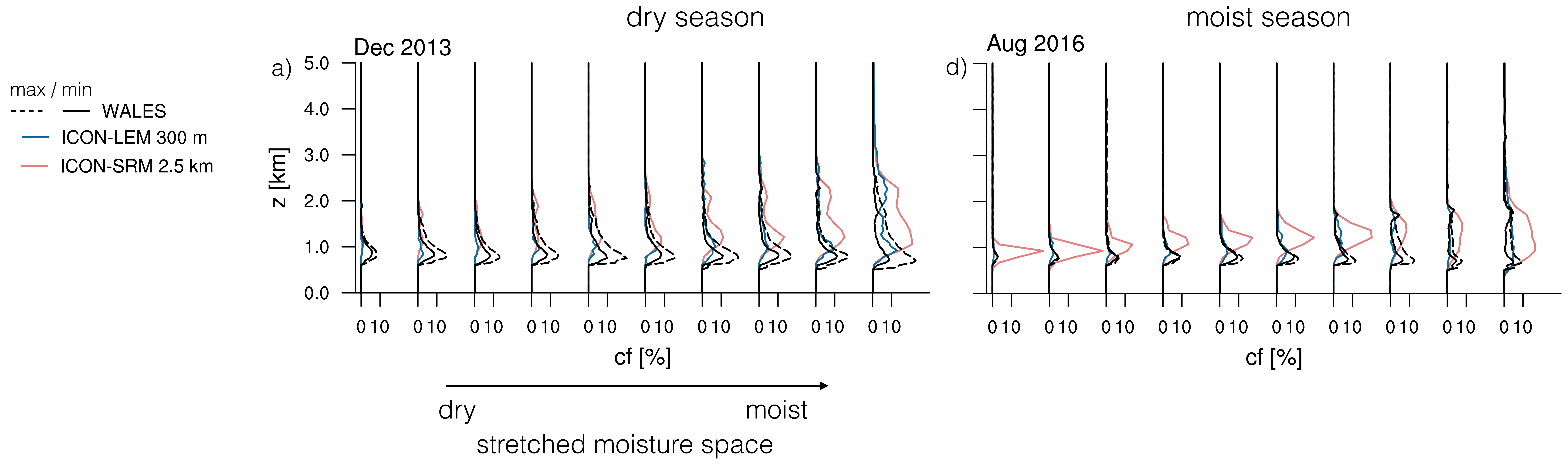
vertical structure of water vapor represented well across moisture space



- moist model bias at the trade inversion across moisture space

- deepening of cloud layer across moisture space captured well

issues in the transition of cloud fraction across moisture space



- cloud deepening with increasing water vapor path is captured well across model resolution

- the concurrent transition from cloud-free to low cloud fraction is better represented at hectometer resolution

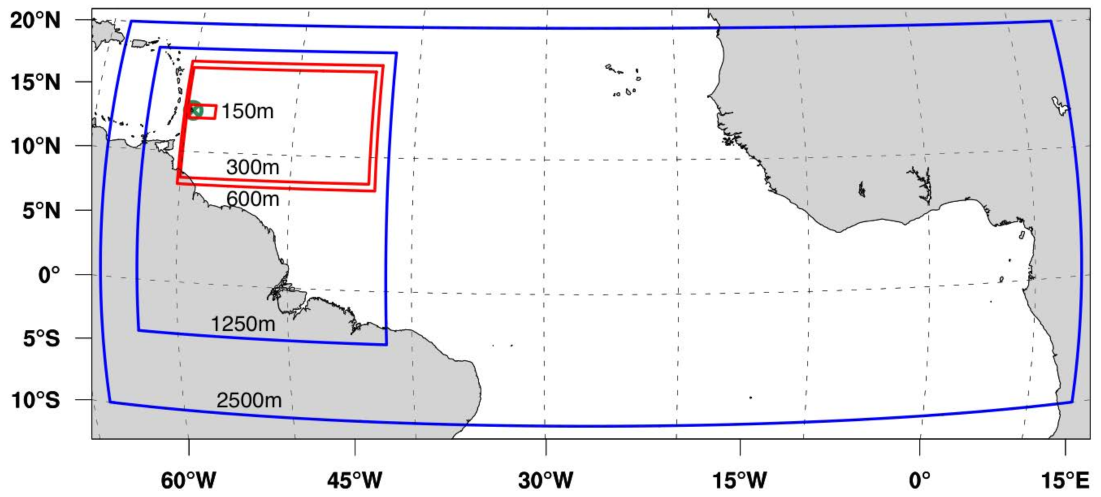
Conclusions

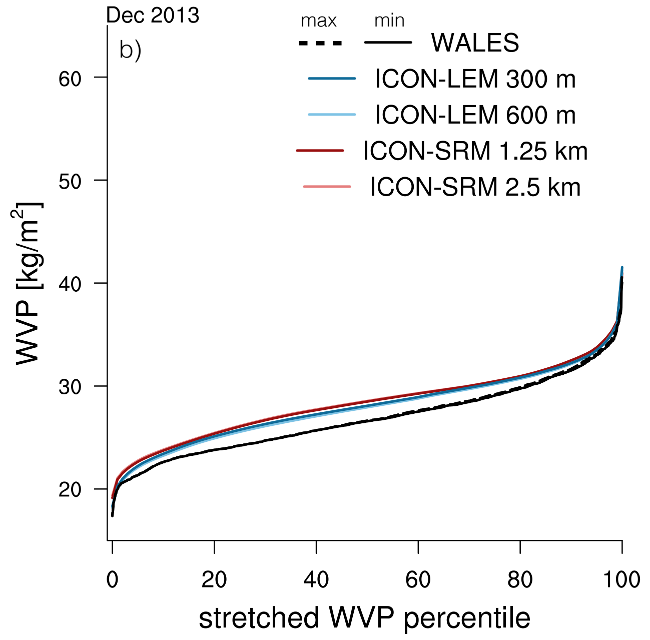
Across model grid spacing from 300 m to 2.5 km, ICON shows a good skill in reproducing airborne lidar measurements of water vapor variability and distribution in the trades.

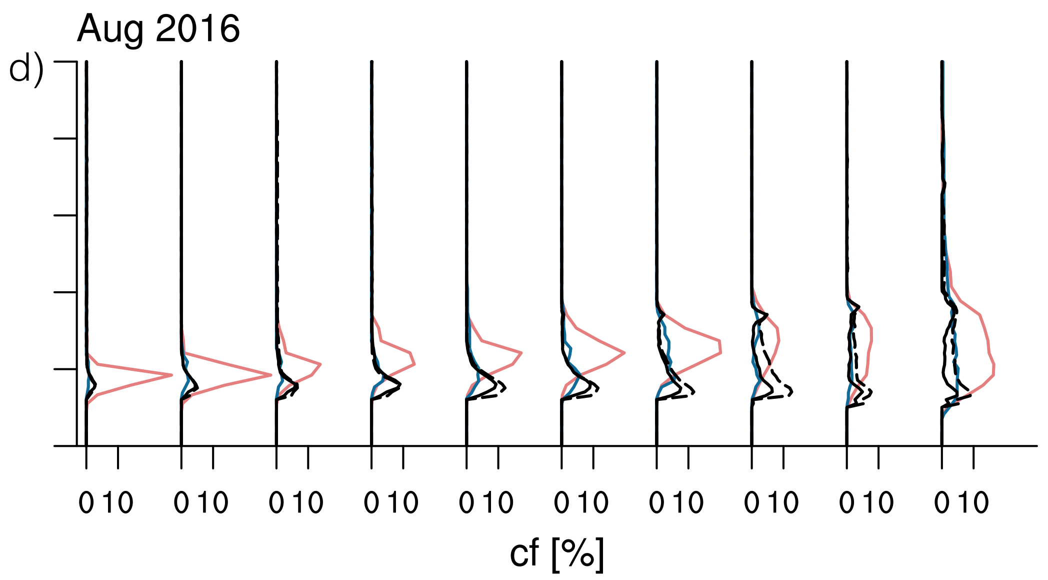
An exception of this is a persistent moist model bias near cloud top in the dry season.

The observed cloud deepening with increasing water vapor path is captured well but the concurrent transition from cloud-free to low cloud fraction is missed at kilometer-scale resolution.

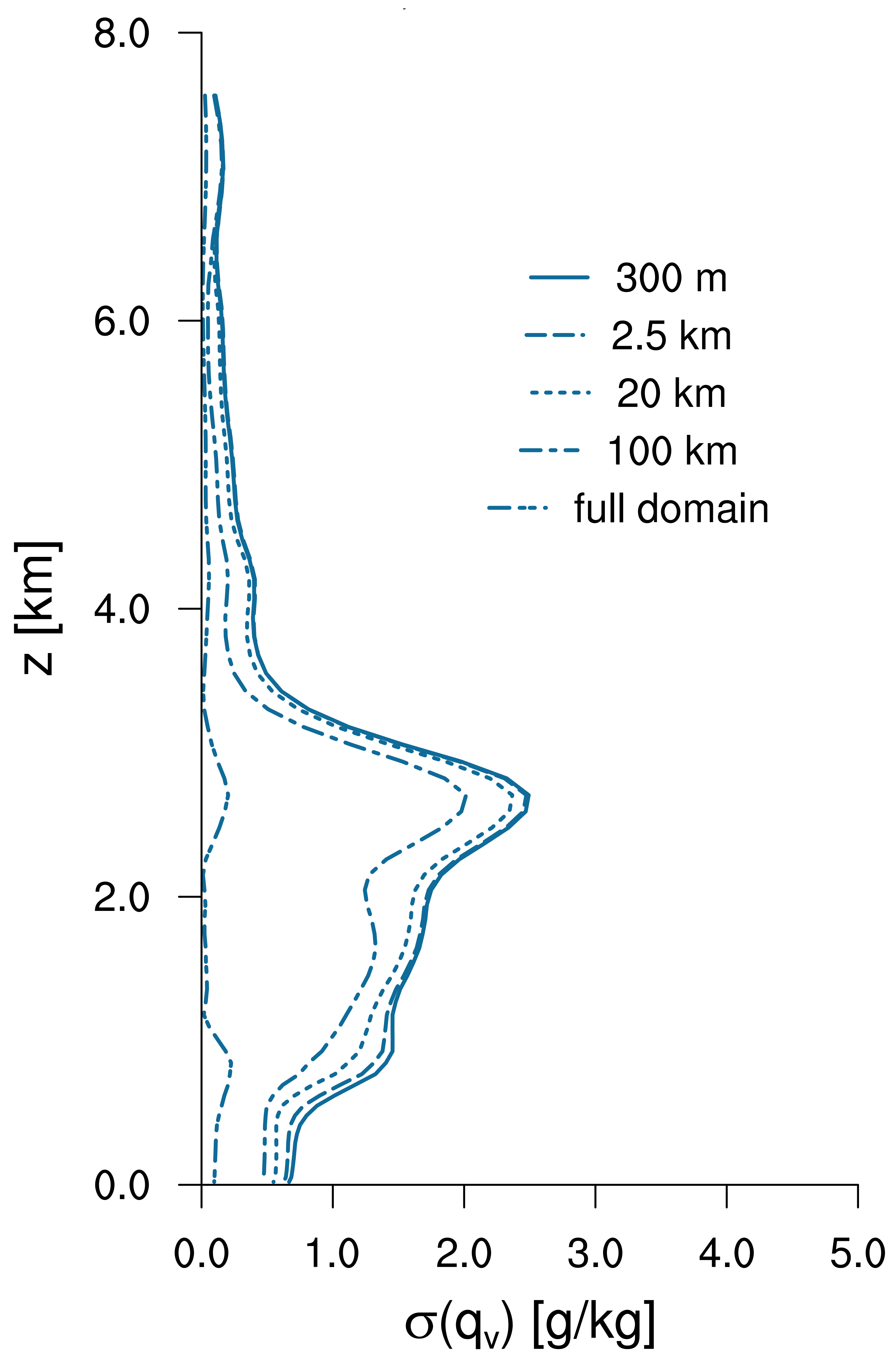
» This is a potential issue for "next-generation climate models" (e.g. DYAMOND, Stevens et al. 2019).







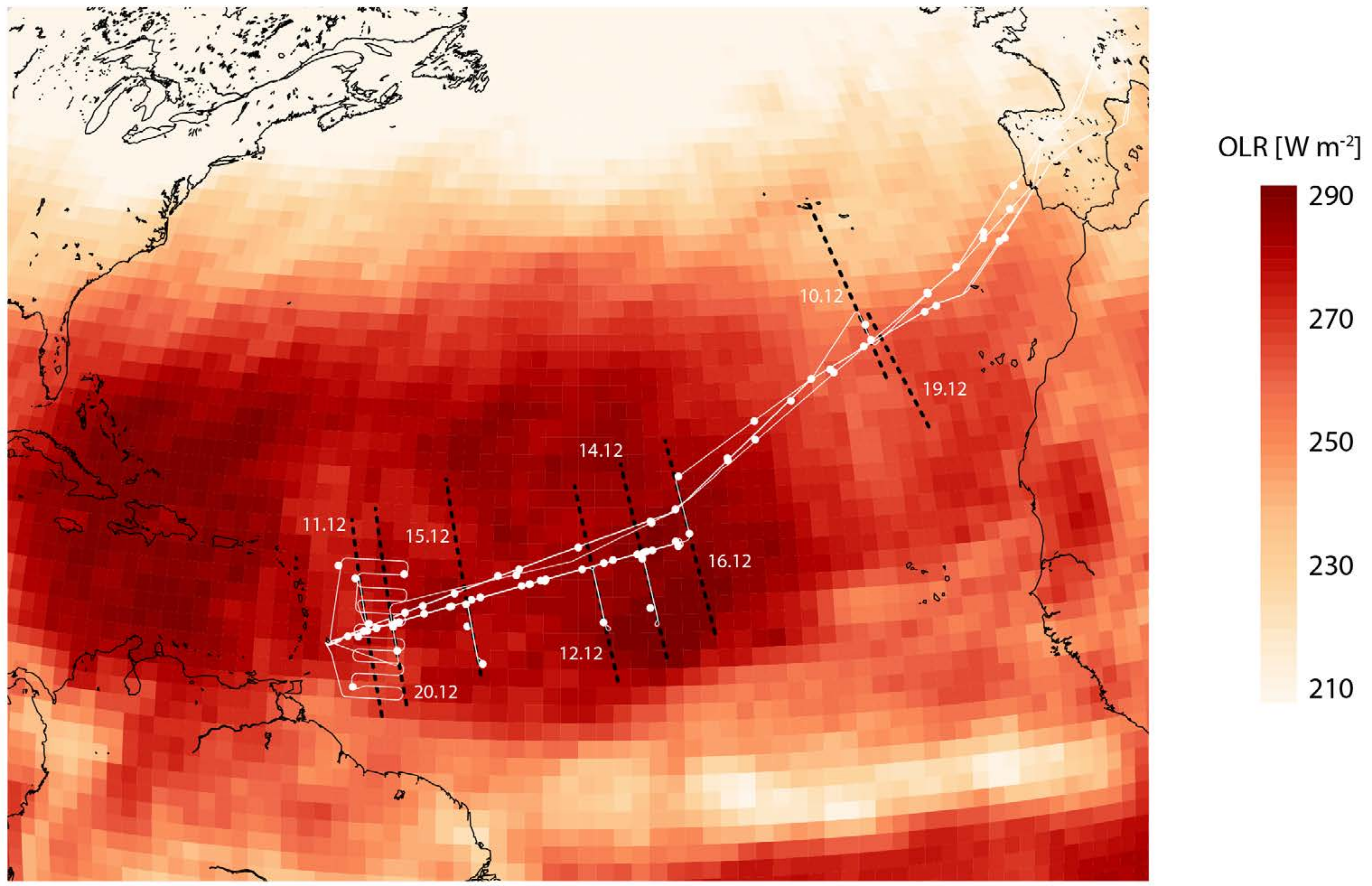
contribution of different scales to the standard deviation of q_v



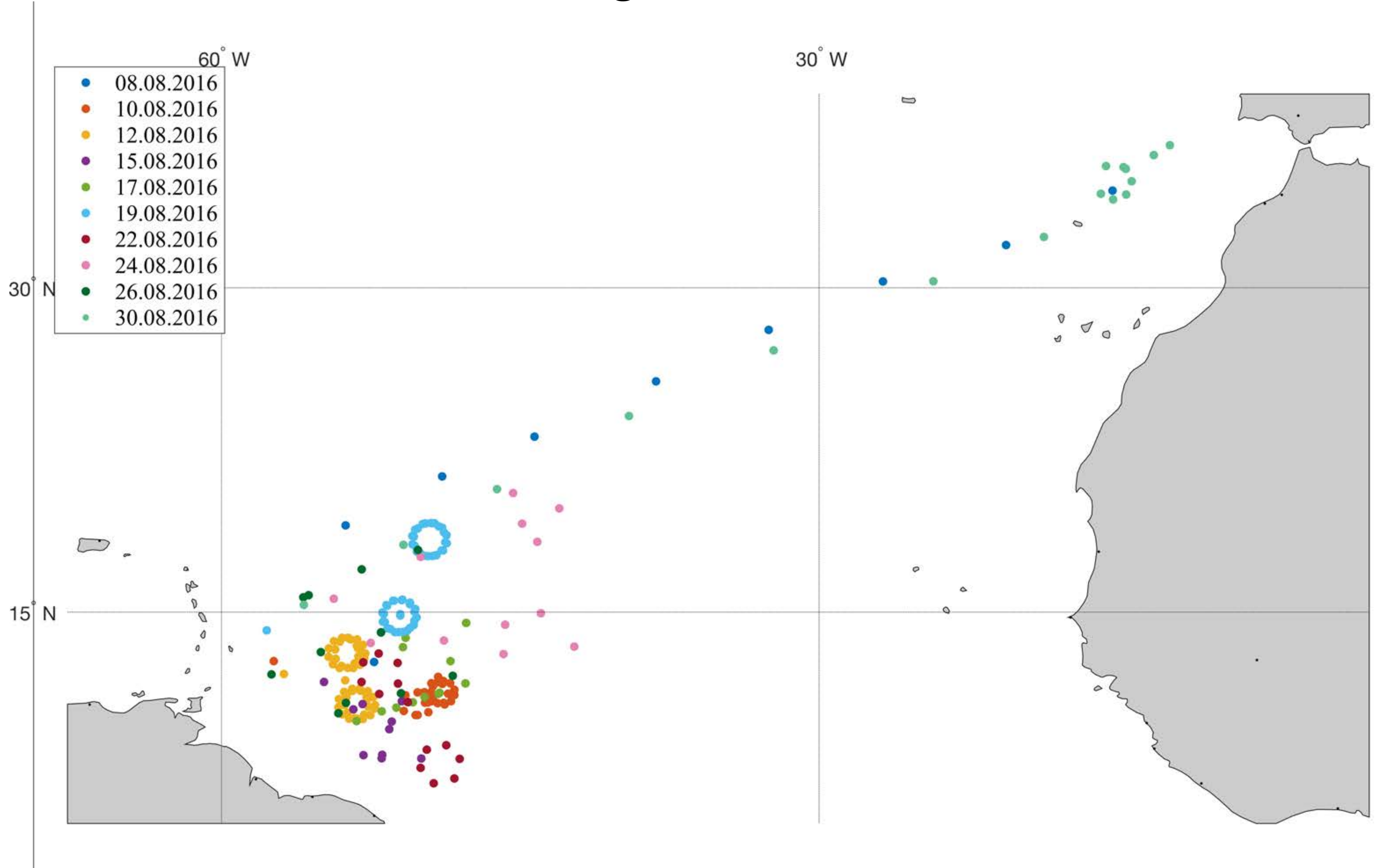
11 December 2013
ICON-LEM 300 m

NARVAL flights

NARVAL-1: December 2013



NARVAL-2: August 2016

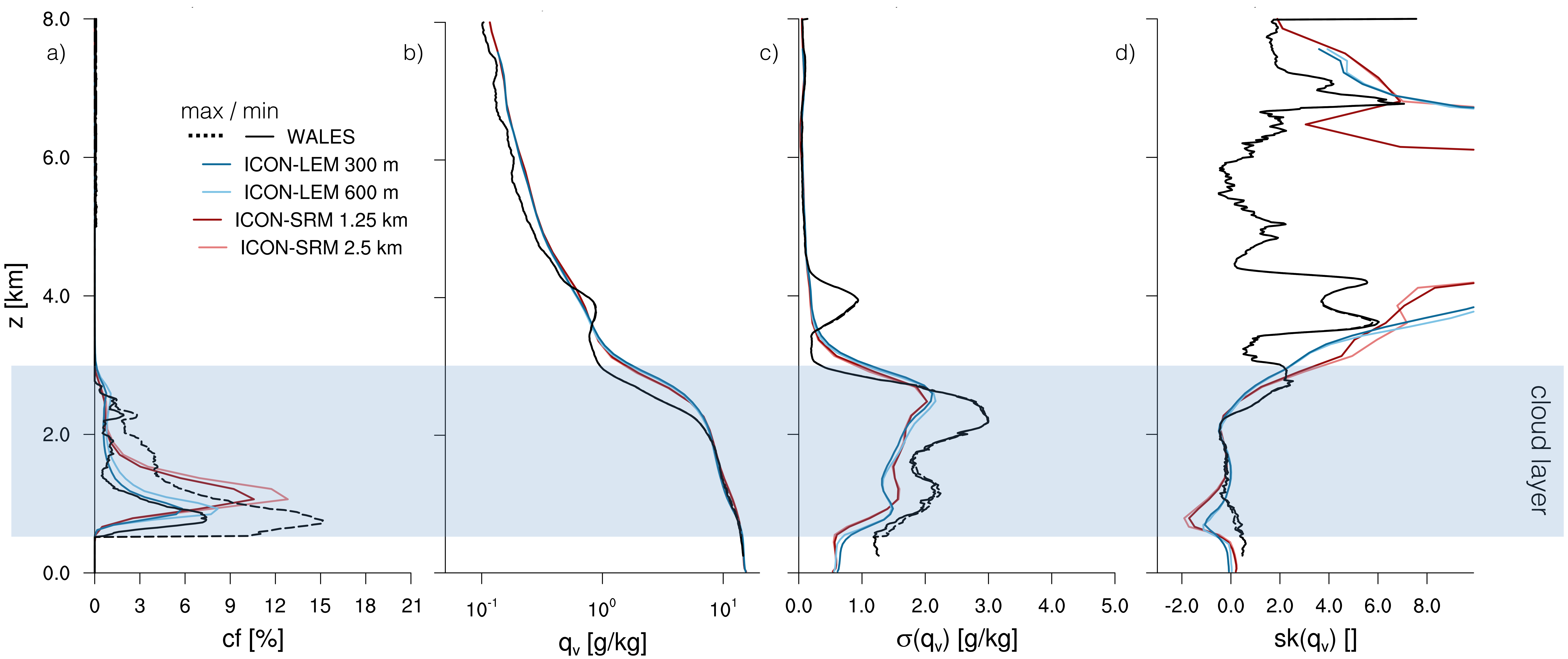


t in UTC	domain	N	p in %	q_c in g kg^{-1}	h_c in km
NARVAL 1					
11. Dec 2013 16 - 21	10.0 - 16.5 N, 58.0 - 55.0 W	537	34.2	4.0	3.0
12. Dec 2013 14-15, 19-20	14.0 - 16.5 N, 56.5 - 48.5 W	526	86.5	4.0	2.8
14. Dec 2013 14-15, 19-20	13.9 - 16.5 N, 57.2 - 48.5 W	296	48.9	4.0	2.5
15. Dec 2013 16 - 21	12.0 - 16.5 N, 57.5 - 48.5 W	668	72.8	4.0	2.7
20. Dec 2013 17 - 18	13.3 - 16.5 N, 56.0 - 51.6 W	168	70.3	4.0	3.0
NARVAL 2					
12. Aug 2016 13 - 19	9.5 - 14.0 N, 55.0 - 52.0 W	1317	69.0	6.0	1.9
19. Aug 2016 13 - 17, 20	13.5 - 16.0 N, 57.0 - 48.0 W	1115	85.4	8.0	2.6
22. Aug 2016 14-15, 20-21	10.0 - 12.8 N, 58.6 - 51.0 W	279	55.9	8.0	1.8
24. Aug 2016 13 - 16	13.0 - 14.5 N, 56.5 - 44.0 W	405	51.3	9.0	1.6

t: time period of analyzed flight, N: number of valid profiles, p: percentage of valid profiles, q_c: water vapor mixing ratio threshold for detecting a cloud top with WALES, h_c: maximum shallow cloud top altitude

vertical structure of moisture in stretched WVP space

11.12.2013



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